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The formulae $\frac{\partial \rho U_i}{\partial t}+\frac{\partial}{\partial x_j}(\rho U_i U_j)=-\frac{\partial P}{\partial x_i}+\frac{\partial}{\partial x_j}\left(\mu\frac{\partial U_i}{\partial x_j}\right)+g_i(\rho-\rho_0)$ *for building* $\frac{\partial}{\partial x_j}(\rho\bar{U}_i\bar{U}_j)=-\frac{\partial P}{\partial x_i}+\frac{\partial}{\partial x_j}\left(\mu\frac{\partial \bar{U}_i}{\partial x_j}-\rho\overline{u_i'u_j'}\right)+g_i(\rho-\rho_0)$ *state of the art* $\frac{\partial}{\partial x_i}(\rho\bar{U}_i\bar{H})=\frac{\partial}{\partial x_i}\left(\lambda\frac{\partial \bar{T}}{\partial x_i}-\rho\overline{u_i'h'}\right)$ *biomedical research facilities.*

Modular Construction for Cleanroom Facilities

Modular cleanroom facilities are an alternative to standard cleanroom facilities that is appealing for several reasons, including shorter onsite construction time and the ability to use materials of construction and material sizes that are impractical for field construction. There are potential drawbacks to consider, however, such as limited ability to factory test some utilities, the potential need to construct a shell building or open the façade of an existing building to slide the modules inside, and tight installation clearances. Although cost savings are often touted as a selling point of modular construction, these savings may not be realized based on a variety of factors. Designers should therefore perform a thorough cost-benefit analysis of modular cleanroom facility types to decide what is most appropriate for the project. The two basic types of modular cleanroom construction are panelized systems and factory-built modular unit systems; this article will review the fundamentals, pros, and cons of each.

Modular Panelized Systems

The site available for project development often precludes the installation of pre-assembled modular solutions. Panelized systems, including cleanroom or walkable cleanroom ceiling panels, liner panels, and modular wall panel systems, may be a good solution in such circumstances. These panels are faced with hard, cleanable materials and are typically gasketed and/or cold-welded to form a contiguous, continuous surface. Panelized systems exceed the quality typical of stick-built field construction because of the availability of ceiling-wall and wall-wall coves and integration with flush window and door systems.

It is important to understand that using a modular panelized system is not as simple as changing architectural finish systems – there is a significant learning curve to implementing them properly, especially for full wall panel systems. For example, most wall panel systems provide a very narrow depth, often 50.8 mm (2”) in overall thickness, which maximizes usable area in the room. However, these systems require significant pre-planning of electrical power and low-voltage systems due to shallow, or in some cases lack of, backbox space. Some manufacturers utilize integral vertical raceways in their panels, but because line and low-voltage systems cannot share the same raceways, coordination is critical and often requires simultaneous consideration of both faces of the wall, especially where devices are desired at the same elevation. It can also be challenging to provide in-service covers for loads which must remain connected during cleaning, as their projection from the surface of the wall makes them particularly susceptible to cart damage. Air and pest-resistant sealing where utilities enter raceways and fire-stopping within raceways can also be difficult to install and inspect properly. Occasionally, terminal devices themselves exceed the available wall thickness. In such cases, custom fabricated stainless steel enclosures, or similar, are installed to provide sufficient mounting depth. Modular panelized systems provide a rapidly installable, hard, cleanable surface, but some are easily damaged, so the installation labor savings may be eroded by operational costs.

Modular Unit Systems

Modular solutions can range from mobile trailers to large, fixed assemblies of “shipping container” type units; the latter are bolted together and can expand over multiple floors with many units per floor, often wrapped within a shell building which serves as the primary weather-resistant envelope for the facility. Typically, the architectural finishes of modular cleanrooms utilize modular panelized assemblies, providing outstanding quality of architectural fit and finish.

Most modular cleanrooms are designed to provide their own air-side HVAC utilities while receiving other utilities, such as electricity, steam, and chilled water, from local sources. While this provides redundancy, reliability, and efficiency, most factories cannot supply these utilities to the pre-assembled modular for Factory Acceptance Testing (FAT) and adjusting, which may result in protracted Site Acceptance Testing (SAT), adjusting, and balancing. In some cases, it is difficult to address design deficiencies that are discovered during SAT due to the compactness of the construction, resulting in potential cost and schedule impacts. Alternatively, mechanical plans could be designed to be less integrated into the site utilities, which shifts the discovery of latent defects more towards the FAT period; however, this may result in increased construction and operating costs. A modular facility’s building automation system (BAS) should be selected and configured for compatibility with the owner’s BAS to ensure connectivity, monitoring and reporting continuity, and operational control. To the extent practicable, probes and sensors should be duct-mounted in accessible locations to facilitate calibration and replacement as necessary without suite entry by facility maintenance staff and contractors during operation. Modular unit systems tend to be expensive, with some savings realized through shorter on-site mobilization.

Conclusion

Modular elements can play a key role in the quest to improve the quality of cleanroom construction. However, they are not a one-size-fits-all solution; careful forethought and planning are necessary to implement them successfully, and the learning curve for designing facilities with modular elements should not be underestimated.

Additional Reading

1. 1. NIH Design Requirements Manual, Chapter 13